HIGH RISE BUILDING MOVEMENT MONITORING USING RTK-GPS (CASE STUDY: MENARA SARAWAK ENTERPRISE)

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To my beloved mother and father

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ABSTRACT

The need for deformation surveys of large engineering structures such as long span bridges, dams and tall structures often arises from concerns associated with environmental protection, property damage and public safety. There are many high buildings nowadays, therefore it is very important to monitor the buildings to ensure they are still under stable condition. Recently, the Global Positioning System (GPS) especially Real Time Kinematics (RTK-GPS) has emerged as a survey tool for many deformation applications. The RTK-GPS is carrier phase observation processed in real time, giving results such as position coordinates. This study highlights the concept and methodology of the continuous RTK-GPS and its potential application for high rise building monitoring surveys. The main objectives of this study are to study the ability and efficiency of the continuous RTK-GPS method in high rise building' deformation detection and also to develop KFilter program for movement monitoring using Matlab v6.1 with Kalman Filter method. The GPS instruments' calibrations had been carried out to ensure accuracy and reliability of the continuous RTK-GPS observation for high rise building movement monitoring. The surveys had been carried out on Menara Sarawak Enterprise, Johore Malaysia in two different epochs. Thus, the developed KFilter program is able to perform the movement monitoring analysis on the observed data to classify the stability of the building. The results of this study shows that the continuous RTK-GPS can provide 1cm and 2cm accuracy for horizontal and vertical respectively. The effectiveness of this technique depends on radio link communication whereby obstructions will cause the communication signal to fail. From the KFilter program analysis, the results shows that the Menara Sarawak Enterprise building is stable. The continuous RTK-GPS epoch 1 and epoch 2 analyses had shown the building is stable although displacement distance around 0.5cm and 1cm respectively are detected.

ABSTRAK

Keperluan bagi melaksanakan ukur deformasi terhadap struktur kejuruteraan besar seperti jambatan, empangan dan bangunan tinggi adalah semakin penting untuk perjagaan alam sekitar dan melindungi keselamatan awam. Terdapat semakin banyak bangunan tinggi pada masa kini, maka amat penting untuk memastikan bangunan tinggi berkenaan dalam keadaan yang stabil. Untuk masa kini, Global Positioning System (GPS) telah digunakan sebagai alat pengukuran bagi kebanyakan kerja-kerja deformasi. RTK-GPS adalah cerapan fasa pembawa yang dijalankan dalam masa hakiki menghasilkan koordinat kedudukan. Kajian ini membincangkan konsep dan potensi aplikasi RTK untuk ukur pemantauan bangunan tinggi. Objektif utama kajian ini adalah untuk mengkaji kebolehan dan keberkesanan bagi teknik continuous RTK-GPS di pengesanan deformasi bangunan tinggi dan membina program KFilter untuk pemantauan pergerakan dengan menggunakan Matlab v6.1 bersama dengan teknik Kalman Filter. Kalibrasi peralatan GPS telah dijalankan untuk memastikan kejituan dan keupayaan cerapan continuous RTK-GPS bagi pemantauan pergerakan bangunan tinggi. Percerapan teknik ini telah dilaksanakan di Menara Sarawak Enterprise dalam 2 epok yang berlainan. Lepas itu, program KFilter digunakan untuk analisis pemantauan pergerakan ke atas cerapan data demi menentukan kestabilan bangunan berkenaan. Hasil kajian ini menunjukkan bahawa continuous RTK-GPS dapat memberi kejituan mendatar 1cm dan menegak 2cm. Keberkesanan teknik ini amat bergantung kepada perhubungan komunikasi radio dimana halangan akan menyebabkan isyarat komunikasi radio terputus. Daripada hasil analisis program KFilter menunjukkan bahawa Menara Sarawak Enterprise dalam keadaan stabil. Analisis epok 1 dan 2 bagi cerapan continuous RTK-GPS mengesahkan bangunan tersebut stabil walaupun jarak pergerakan lebih kurang 0.5cm dan 1cm telah dikesan dalam kedua-dua epok.

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LIST OF ABBREATIONS

GPS	Global Positioning System
Hz	Hertz
RTK	Real Time Kinematics
cm	centimeter
mm	millimeter
m	meter
hr	hour
PRN	Pseudo Random Noise
ppm	Part per million
DSMM	Department of Survey and Mapping Malaysia
TGO	Trimble Geomatics Office
DOP	Dilution of Positioning
RMS	Roof Mean Squares
OTF	On-the-fly
B1	Base 1
B2	Base 2
R1	Rover 1
R2	Rover 2
WGS84	World Geodetic System 1984
cont.	continuous
LSE	Least Square Estimation

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Deformation refers to the changes which a deformable body undergoes in its shapes, dimension and position. Deformation survey can be used for obtaining information about the stability of some objects like natural or man-made objects. The man-made objects such as large engineering structures are subject to deformation due to various factors: changes of ground water level, tidal phenomena, tectonic phenomena, land movements, or any other natural disasters. The large engineering structures include dams, long span bridges, high rise buildings, reservoirs, sport domes, planetariums, Olympic stadium etc. Therefore it is important to measure this movement for the purpose of safety assessment as well as to prevent any disaster in the future.

A high-rise building is defined as a building 35 meters or greater in height, which is divided at regular intervals into occupiable levels (Emporis, 2004). To be considered a high-rise building an edifice must be based on solid ground, and fabricated along its full height through deliberate processes (as opposed to naturally-occurring formations). A high-rise building is distinguished from other tall man-made structures by the following guidelines

i. It must be divided into multiple levels of at least 2 meters in height;
ii. If it has fewer than 12 such internal levels – see Figure 1.1, then the highest undivided portion must not exceed 50% of the total height.

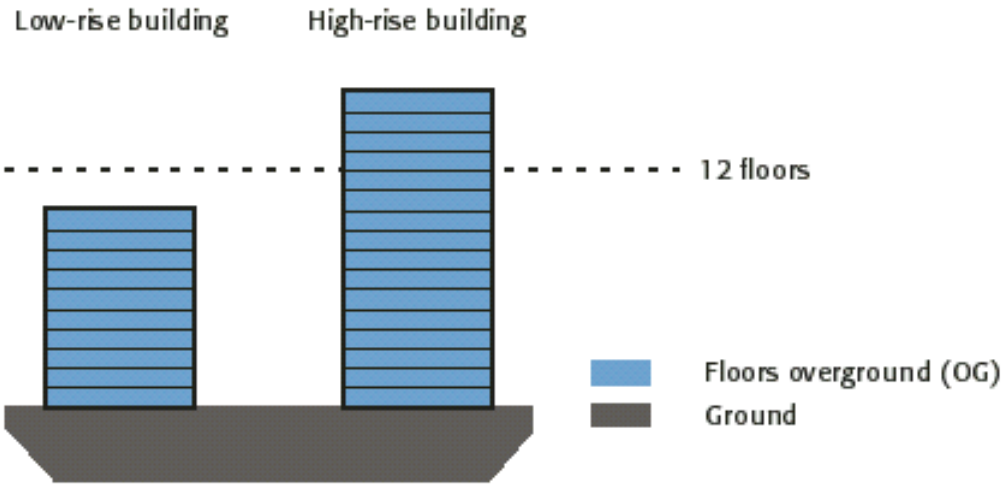

Figure 1.1: General Definition of High-rise Building (Emporis, 2004)

Nowadays, there are much more large and tall engineering structures (high rise buildings) than the past. These structures are designed to be much more flexible and to resist extensive damage from changes in temperature, severe wind gusts and earthquakes. Structural engineers require precise, reliable instruments to resolve their concerns about angular movements, displacements and structural vibrations. Hence, some actions can be taken before the disasters strike. It can save lives, avert large financial liabilities and avoid severe environmental damage.

In general, there are two types of technique in deformation survey, i.e. geodetic surveys and non-geodetic survey (geotechnical and structural). Geodetic survey using total stations, precise levels, Global Positioning System (GPS), etc can be based on absolute and relative networks. Deformation detection via geodetic method mainly consists of two step analysis independent least square estimation (LSE) of each epochs followed by deformation detection between two epochs. On the other hand, geotechnical and structural methods use special equipments to measure changes in length (extensometer), inclination (inclinometer), strain (strainmeter) etc.

In contrast, the GPS technology can measure directly the position coordinates and nowadays relative displacements can be measured at the rate of 10Hz or higher. This provides a great opportunity to monitor, in real time, the displacement or

deflection, behavior of engineering structures under different loading conditions, through automated change detection' and alarm notification procedures (Ogaja et. al., 2001).

One of the most recent real time GPS techniques to date is RTK-GPS. Such real-time application had been widely used in various survey applications and navigational purposes, regardless on land, at sea or in the air (Rizos, 1999). RTK-GPS can achieve the accuracy of ± 2 cm + 2 ppm. In RTK-GPS configuration, a receiver is placed on the reference point with known coordinates as reference station. This reference station will continuously transmit correction message to rover receiver. For example, a fully automated monitoring system using RTK-GPS technique had been implemented successfully in Dam Diamond Valley Lake, California. This system will provide the information on the displacement of the monitoring points weekly (Michael et.al., 2001).

High rise building research was carried out at Menara Sarawak Enterprise which is located at Stulang Laut, Johor Bahru (see Figure 1.2). The height of the building is almost 120m above ground. The building's structure is consisted of 30 storey tower and 3 basements as car park level. Each storey is about 3.5 meters in height.

Figure 1.2: *Menara Sarawak* Enterprise

1.2 Problem Statement

Since our national high rise buildings inventory are aging and they are carrying more and more loads, the need to monitor high rise buildings' performance has increased significantly over the past few years. High rise buildings require careful provisions of life-safety systems because of their height and their large density of occupant. Therefore, both for maintenance and repair planning, high-rise building monitoring is becoming increasingly important. What's more, structural deformation and deterioration problems faced by the high-rise building authorities are very similar to those faced by dam, large span bridge, and highway and railroad authorities.

In satellite surveying, static GPS positioning technique is perhaps the most common method used by surveyors because of the high accuracies it can obtain. In general, one to two hours is a good observation period for Static GPS baseline up to 30 kilometers. Static GPS method can be used for deformation detection. However, this method is not suitable for continuous deformation monitoring because Static GPS methods cannot provide data continuously compared to Real Time Kinematics (RTK) GPS positioning technique. A high precision, carrier phase based, RTK-GPS has been considered to play an important role as an alternative technique to the geotechnical methods or in addition to such a sensor (Ogaja, 2000). The notable advantage of using RTK-GPS is that this technique can detect deformation if the structure has drifted (a few cm) relative to some reference or baseline while accelerometers can not detect, directly, the absolute or relative displacements of the structure (Ogaja, 2000). Therefore, the aim of this study is to analyze the potential application of RTK-GPS method in deformation monitoring purpose of high rise building.

1.3 Research Objectives

The objectives of this study have to fulfill the following requirements:-

i. To study the ability and efficiency of the continuous RTK-GPS method in high rise building's deformation detection.
ii. To develop program for monitoring movement using Kalman Filter algorithms.

1.4 Research Scopes

The research scopes of this study involve:-

i To carry out the GPS data observation in continuous RTK-GPS technique
ii. To process and analyze the data in order to get the pattern and magnitude of the deformation.
iii. To study the ability of RTK-GPS to be applied in high density construction area.

1.5 Significance of Study

The significance of this study includes:-

i Develop a RTK-GPS movement monitoring system with the aid of Kalman Filter on high rise building.
ii Determine the type of the errors caused by RTK-GPS observation in movement monitoring.

1.6 Research Methodology

Research methodology is divided into a few stages in order to achieve the objectives of this study (see Figure 1.3).

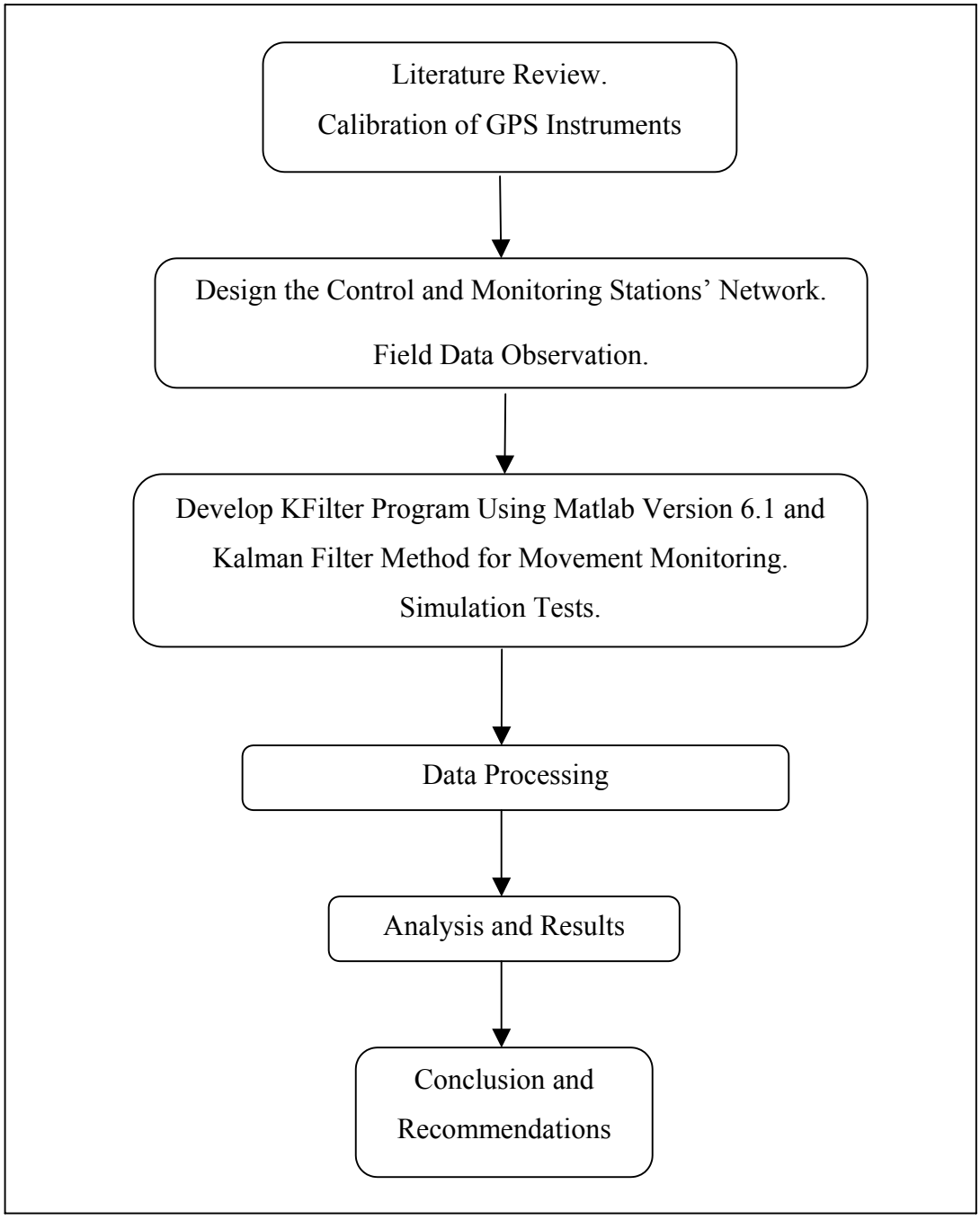

Figure 1.3: Flow of Research Methodology

1.6.1 Literature Review

Literature reviews were carried out on the concepts of GPS, deformation surveying, structural monitoring, and the understanding of the GPS instrumentation. Calibration of GPS instruments (Trimble 4800 series and Leica System 500) had been carried out to ensure the instruments in good condition to perform the GPS observations. At this stage, the GPS instruments were studied to ensure the instruments can carry out continuous Real Time Kinematics technique with one second sampling rate. Both of them are dual-frequency (L1 and L2) and able provide high precision results.

1.6.2 Field Data Acquisition

Before field data acquisition has been carry out, the control network and monitoring stations should be designed and placed in suitable locations. In this study, Trimble 4800 series and Leica System 500 observations had been used to carry out for two epochs. First epoch had been carried out on 21 December to 23 December 2004 whereas the second epoch had carried out on 28 April 2005 to 29 April 2005.

1.6.3 Development of KFilter Program

KFilter program had been developed using Matlab version 6.1 and based on the Kalman Filter algorithm for the object movements monitoring purpose. The program will read continuous RTK input data from GPS receiver and performs movement monitoring analyses with the help of Kalman Filter algorithm. The program will give some warning alarms if it detected displacements from the observed data. Beside that, the simulation tests had been carried out to ensure the reliability of the developed KFilter program in movement monitoring.

1.6.4 Observation Data Processing

The observed data had been processed using certain commercial software or self-developed program. The continuous RTK data had been downloaded to Leica SKI-Pro and Trimble Geomatics Office. The output files with its suitable format for the developed program will be created. The program which is developed using Matlab v6.1 will perform its analysis based on the observation data.

1.6.5 Analyses and Results

Analyses in this study include the reliability of the observed data and the effectiveness of the program in determining the stability of the high rise building. In this study, the program will perform structural monitoring analyze on the GPS observation data.

1.6.6 Conclusions and Recommendations

Summarizes findings, make conclusions and recommends topics for further investigations. The prospects and limitations of continuous RTK-GPS technique were also presented.

1.7 Thesis Overview

Chapter 1 described the important of the deformation monitoring for high rise building using Global Positioning System (GPS). The problem statement, research scopes and the significant of the study had been described.

Literature review is an important stage of this study to ensure that the research can be carried out successfully. It was discussed in Chapter 2. The types of material of high buildings were stated out in this chapter. The factors that affect concrete strength of the buildings were explained. The RTK-GPS was used in this study for movement monitoring. Thus the introduction and literature review on the RTK-GPS were stated out. There were included the errors of RTK-GPS observation and its configuration.

The program for movement monitoring with the help of Kalman Filter method had been developed. Therefore, the introduction and definition of the Kalman Filter method including its algorithms were elaborated in Chapter 3.

The calibration of GPS instruments and field data acquisition is the most important stage in the study and discussed in details in chapter 4. 2 epochs of observation were carried out in the study. Setting up a deformation network which consists of selected reference stations and the monitoring points is necessary. The GPS observations were carried out using GPS instruments, Leica GPS System 500 and Trimble GPS 4800 System. Meanwhile, the software used for data downloading and data processing were Trimble Geomatics Office and Leica Ski-Pro. The simulation test was carried out to ensure that the developed program can detect the displacement or vibration successfully.

Chapter 5 discussed the calibration and simulation tests analysis results. Besides that, the stability analysis of Menara Sarawak Enterprise using developed program had been carried out. The analysis was verified by other program, such as GPS Deformation Analysis Program-Bayrak (Turkey) and GPSAD2000-Boon (Malaysia). This increased the reliability of the analysis for Menara Sarawak Enterprise movement monitoring.

Lastly, chapter 6 presented the conclusions of this study. Some recommendations had been proposed and considered to improve this study.

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